Effects of Prescribed and Wildland Fire on Aquatic Ecosystems in Western Forests

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Abstract: Prescription burning and Fire Management Plan - approved wildland fires are increasingly important management tools used to reduce fuel loads and restore the ecological integrity of western forests. However, the effects of prescribed fires, fire suppression, and stand-replacing fires (= wildland fires) on aquatic ecosystems are not yet understood. The goal of this study is to quantify and compare the ecological consequences of (1) unburned forests (fires absent for at least 70 yrs), (2) prescribed understory fire, and (3) stand-replacement fire. Four primary stream indicators will be used: amphibians, aquatic macroinvertebrates, periphyton, and stream conditions (temperature, chemistry, discharge, sedimentation, and large woody debris). The effects of prescribed fire fuel manipulations will be evaluated in controlled natural experiments in Ponderosa Pine/mixed coniferous forests in watersheds in the South Fork Salmon basin in central Idaho and in mixed coniferous/hardwood forests in the Siskiyou Mountains in southwestern Oregon. The effects of wildland fires (1-15 years old) will be evaluated in paired creeks (burned, unburned) in (1) Big Creek drainage, Frank Church-River of No Return Wilderness, central Idaho, (2) Bitteroot River drainage, western Montana, (3) Rogue River, Siskiyou Mountains near the Oregon- California border, (4) Umpqua River, southwestern Oregon, and (5) Wallowa Mountains, northeastern Oregon. The proposed research directly addresses the RFP Task 3 to determine the cumulative effects of fuels manipulation/reduction methods on wildlife population and habitat structure dynamics, and ecosystem health. The results of this study will provide critical information necessary for managers to (1) evaluate the immediate and long-term effects of alternative fire management activities on stream ecosystems, (2) assess how fire management affects the ecological integrity of aquatic ecosystems, and (3) identify potential opportunities to better manage for Threatened and Endangered aquatic species.

Project Justification

In the mountainous regions of the western U.S., wildland fires are a natural disturbance that have been aggressively suppressed in recent decades, resulting in changes in forest ecosystems, including productivity, nutrient cycling, and the structure, composition and spatial patterning of vegetation (Christensen 1988, Arno et al. 1995). With an increased awareness of the importance of fire for maintaining healthy forests, attitudes about fire management have changed, and fire is being reintroduced into the landscape through prescription burning and Fire Management Plan - approved wildland fires. Despite the increased use of fire as a forest restoration tool, there is inadequate information on the effects of prescribed and wildland fires on the numerous plants and animals that occupy the forests being restored, particularly in lotic (stream) ecosystems (Potter and Kessell 1980, Smith 2000).

The few studies of fire effects on lotic systems to date have been conducted within single drainages, have focused on stand-replacing wildland fires, and few have included an experimental component, such as prescribed burns (see Major and Bury 2000). Further, most fire studies lack adequate design and replication at local and regional scales. In particular, studies need to address the relative effects of prescribed and wildland fires at broader spatial scales. This study, which combines an on going prescribed fire study with post-fire investigations of lotic ecosystem responses to wildland fires, provides a unique opportunity to characterize the effects of fire treatments and severity on aquatic ecosystems at multiple spatial scales (streams to watersheds to regional forests).

The lack of information on the effects of fire on fish and aquatic wildlife is a major impediment to developing ecologically sound fire management policies (McMahon and deCalesta 1990). Although some studies have examined the effects of fire on invertebrates in lotic systems, better information on invertebrate responses to prescribed fire is needed. Almost nothing is known about the responses of amphibians to fire and fire management (DeMaynadier and Hunter 1995, Russell et al. 1999). The proposed research would represent the first quantitative examination on the effects of fire management practices in headwater streams in the forested West. Because several amphibian species in the mountainous regions of the western U.S. are declining, understanding the effects of fire on amphibians and amphibian habitats is increasingly important. Because biotic communities often respond to disturbances, such as fire, in complex ways, monitoring wildlife populations in the context of ecosystem processes and habitat structure dynamics is important. Therefore, we propose to take an ecosystem approach to studying the effects of prescribed and wildland fire on lotic communities by monitoring amphibians, invertebrates, periphyton, instream abiotic conditions, and riparian forests.

This study will directly address Task 3 of the Request for Proposals, to determine the cumulative effects of fuels manipulation/reduction methods on wildlife population and habitat structure dynamics, and ecosystem health. Results from this study will help managers evaluate the effectiveness of applying fuels reduction treatments and assess the ecological trade-offs associated with various fire conditions, such as potential conflicts among aquatic TES habitat requirements and fuels management. Thus, by addressing the ecological consequences of various fire conditions, the proposed study will help expand on the current emphasis of fire management for fuels reduction.

Project Objectives

This study will have two major components: prescribed fire and wildland fire. First, we will conduct a controlled experimental prescribed fire study to evaluate the effects of fuel reduction practices on aquatic ecosystems. The second part of this study will assess the effects of wildland fire on stream ecosystems in watersheds that burned 1-15 years ago with unburned watersheds. This two-part approach will enable us to evaluate whether prescription burning simulates wildland fire in terms of aquatic ecosystem responses.

We propose research that addresses three underlying hypotheses and related management questions:

1. How do amphibian, macroinvertebrate, and periphyton communities respond to prescribed and wildland fire practices?
2. Do these biotic communities respond differently to high-frequency/low-severity fire (understory burns) versus low-frequency/high-severity fire (stand-replacement burns)?
3. What stream habitat parameters are associated with abundant amphibian and invertebrate populations, and how are they affected by burning treatments?

To address each of these hypotheses, we will quantify the following components of lotic ecosystems in all watersheds in the study areas:

a. Density and biomass of 2-4 species of endemic stream amphibians;
b. Composition and abundance of the aquatic invertebrate community;
c. Density and productivity of the benthic periphyton community;
d. Selected stream conditions including temperature, chemistry, discharge, sedimentation, and large woody debris; and
e. Riparian forest structure and composition

Information from this proposed work will be used for evaluating prescribed fire projects through National Environmental Policy Act (NEPA) analyses, appeals and litigation, subbasin reviews, watershed analyses, forest plan revisions, long-term monitoring strategies, and consultations, including recovery plans, biological assessments, biological evaluations, and biological opinions. Thus, by providing information on the effects of prescribed burning and wildland fires on lotic ecosystems, this study will help determine the cumulative effects of fuels manipulation and reduction methods on future landscape characteristics involving wildlife populations, habitat structure dynamics, hydrologic effects, soil effects (inputs into streams), and ecosystem health issues.

Background

A limited body of research has been compiled regarding the effects of wildfires on lotic biota (Roby and Azuma 1995, Minshall et al. 1997, Rieman et al. 1997, Smith 2000). In general, fire is considered to ultimately benefit aquatic organisms, even among species that are negatively affected by the disturbance immediately after the fire. For example, aquatic invertebrates may decline immediately after a fire, and then increase to levels above pre-fire conditions as a response to increased stream productivity (Lyons et al. 1978). However, large fires can have long-term effects on invertebrate community structure, reducing invertebrate diversity for a decade or longer (Roby and Azuma 1995). Long-term fire effects in aquatic habitats include changes in peak discharge, stream channel morphology, large woody debris availability, sediment load, temperature, and water chemistry (Richards and Minshall 1992, Minshall et al. 1997). Also, the effects of fire on stream biota may be more pronounced in headwater streams than in mid-order or larger streams (Minshall et al. 1989, Roby and Azuma 1995, Minshall et al. 1997).

Recent reviews of the effects of fire on amphibian communities uncovered relatively few studies, and most of these were conducted in eastern pine plantations (Russell et al. 1999). Amphibian populations should respond positively to increased productivity (periphyton growth), but they are also sensitive to water velocity, temperature, chemistry, substrate size, and sedimentation (Corn and Bury 1989, Gamradt and Kats 1997). Some stream amphibians, like the tailed frog (*Ascaphus* sp.), are particularly sensitive to elevated temperature, and die quickly when exposed to water temperatures at or near 29.6°C (see deVlaming and Bury 1970). Although direct mortality of aquatic and wetland-associated life stages of amphibians may be low where wet areas (e.g., riparian zones) provide suitable refugia from fire (Vogl 1973), terrestrial life stages in uplands may experience much higher mortality associated with the direct and indirect (e.g., prey availability, shelter, microclimate) effects of fire (Russell et al. 1999). Further, physical and biological changes in adjacent uplands may influence the survival and well being of biota in riparian zones through changes in hydrology and water chemistry in the streams.

This study will provide important information for evaluating the effects of fire and forest management practices on several amphibian species. In Idaho, two stream-breeding amphibian species occur in the study area, Idaho giant salamanders (*Dicamptodon aterrimus*) and Rocky Mountain tailed frogs (*Ascaphus montanus*). Both of the species were recently described as new species and are endemic to the Northern Rocky Mountains. In Oregon, we will study the Pacific giant salamander (*D. tenebrosus*), tailed frog (*Ascaphus truei*), and torrent salamander (*Rhyacotriton variegatus*). All of these species require rocky headwater streams, and are sensitive to disturbance (Corn and Bury 1989; Welsh and Ollivier 1998), except giant salamanders that tend to have broader tolerance to temperature and other factors in streams.

Riparian areas are typically avoided in prescribed burn projects. However, the lack of fire in riparian areas may create fuel build-ups that lead to unnaturally severe fire in riparian zones, especially in the more productive sites at lower elevations (Barrett 2000). Further, disruption of the fire regime likely results in changes in riparian forest structure and composition. Thus, fires influence instream woody debris dynamics and, in turn, channel processes and habitats of aquatic organisms. The relationship of riparian forest conditions and instream large woody debris, and changes in this relationship associated with time since disturbance, are largely unknown in low elevation forests in the western United States.

The Idaho portion of our proposal is linked to an ongoing Rocky Mountain Research Station experiment to evaluate fuel reduction and forest restoration strategies to sustain wildlife and fish habitat in Ponderosa Pine forests in the South Fork Salmon River (Saab et al. 2000). Riparian areas in the South Fork Salmon subbasin have generally not experienced fire for at least 75 years, although the mean fire interval for riparian areas in this subbasin is 14 years (Barrett 2000). As a result of fire exclusion and a lack of prescribed burn projects in riparian areas, the stage is being set for unnaturally severe fires in these areas (Barrett 2000). However, before embarking on widespread prescribed fire projects in riparian areas, research and monitoring should be conducted to evaluate the effects of fuel reduction and forest health treatments on amphibians, aquatic invertebrates, and the potential for improving habitat for aquatic organisms in general. For example, many headwaters and small streams are critical to the survival of TES salmonid species in downstream, larger waters, such as the chinook salmon, steelhead, bull trout, and westslope cutthroat trout.

The timing of the proposed research and other studies being conducted in the Northwest, offer many opportunities for collaboration and comparison of results at broader spatial and temporal scales. To do this effectively, we will be using and developing similar amphibian, invertebrate, and periphyton sampling methodology as other scientists. For example, we hope to collaborate with Wayne Minshall in the Big Creek drainage, Idaho. Rita Dixon (IDFG, Lewiston) will be starting a pilot study to look at the effects of the Maloney Creek fire on amphibians in the Craig Mountain Wildlife Management Area in the Salmon Subbasin. We also hope to coordinate with John Lehmkuhl who will be conducting similar fuel reduction investigations on the Okanogan National Forest in Washington State in the next several years. Due to support in the past (10 small to moderate-sized projects), we expect to increase sample sizes (# of streams) in BLM Districts and National Forests in southern Oregon. Once we have a core team hired, it is highly cost effective to add summer stream crews for sampling in additional sites and watersheds.

Further linkage and ties will occur. Two of us (Bury and Corn) are P.I.s on the national Amphibian Research Monitoring Initiative (DOI supported). We will be developing a network of long-term monitoring sites for stream amphibians. These could serve as "controls" or further sites to compare to treatment (burned) streams herein. We are currently advising on amphibian surveys and long-term monitoring needs for the Northwest component of the new Inventory and Monitoring program, National Park Service. Again, we would encourage close collaboration to benefit from landscape and regional comparisons of studies. For example, one team (Bury, Mike Adams at FRESC) is providing input to 'Vital Sign' workshops for Olympic, Mt. Rainier and Redwoods National Parks, Whiskeytown National Recreation Area (CA), and others.

Materials and Methods

We will use a multi-scale approach to compare treatments: (1) within streams; (2) among streams within local regions; and (3) across the northwestern United States (Table 1, Fig. 1). A common experimental and sampling design is shared for all watersheds. Paired units or replicates will be selected for monitoring at geographic units (Idaho/Montana, Oregon). These will be selected on the basis of prescribed fire opportunities and priorities that were identified by local USFS and BLM Districts. Burn plans will be written to accommodate both fall and spring fire conditions. These plans will target the killing of small trees < 15 cm diameter breast height and those within

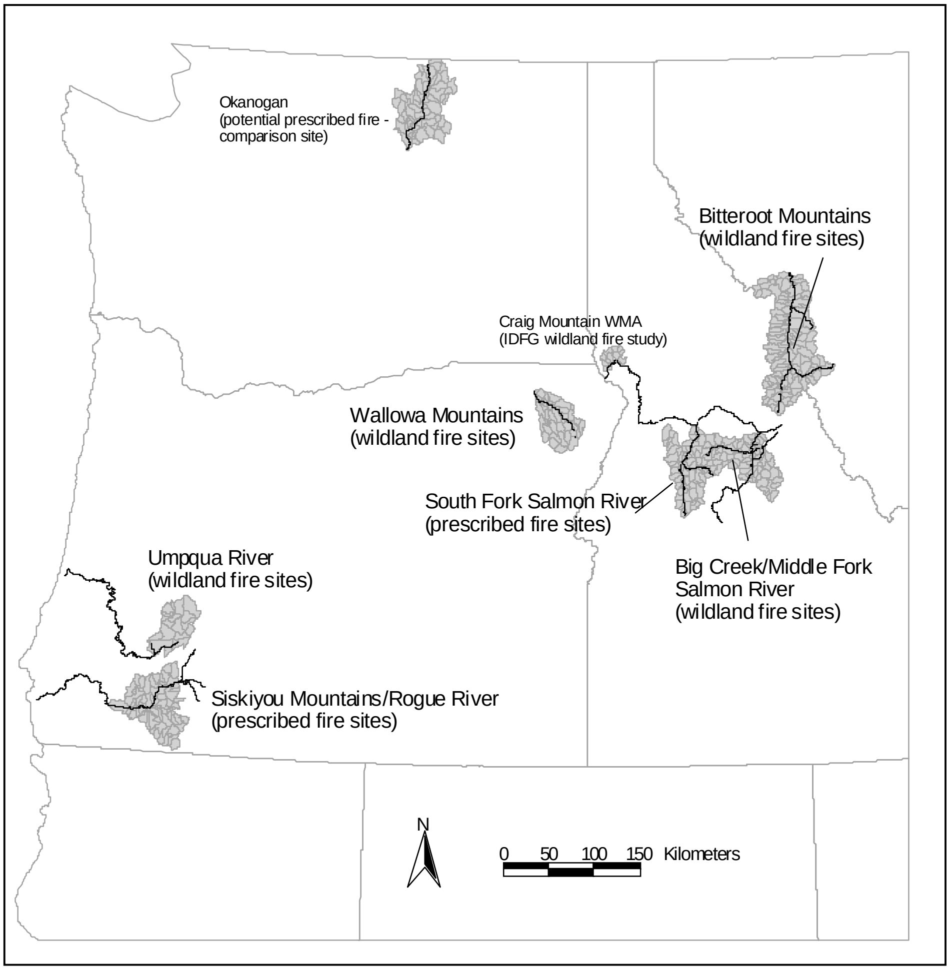

Figure 1. Map of the proposed study areas in Idaho, Montana, and Oregon. The black lines are major rivers and gray polygons delineate hydrologic unit 6's in geographic areas where streams will be monitored for amphibians, invertebrates, periphyton, and aquatic and riparian conditions.

Table 1. General locations and administrative units of study sites.

Study Type	Study Area	Streams Burned	Streams Unburned	Administration	State
Prescribed Fire	South Fork Salmon River Subbasin	3	3	Payette Nat. Forest	Idaho
Wildland Fire	Big Creek drainage, MF Salmon River Subbasin	6	6	Payette Nat. Forest	Idaho
Wildland Fire	Bitteroot Mtns. in Bitteroot River drainage	6	6	Bitteroot Nat. Forest	Montana
Prescribed Fire	Siskiyou Mtns. in Rogue River drainage	3	3	Rogue R.N.F.; BLM Medford	Oregon
Wildland Fire	Cascade Mtns. in North and South Fork of Umpqua R. drainages and Siskiyou Mtns. in Rogue R. drainage	6	6	Umpqua&Rogue R. Natl. Forests; BLM Roseburg and Medford	Oregon
Wildland Fire	Wallowa Mtns.	6	6	Wallowa Nat. Forest	Oregon

clumps. Ground and needle litter will also be targeted for consumption. Methods of ignition will include both aerial (PSD and helicopter) and ground (drip torch). Timing of the burns will be weather dependent. Areas with riparian areas may have adjacent upland slopes (e.g., Ponderosa Pine, mixed conifer-hardwood) burned in the spring to provide buffers for the riparian burns in the fall. Each of the planned burns will be evaluated and agreed upon with the monitoring program to develop the best method to meet the project objectives.

Idaho and Montana Study Areas**:** We will monitor the effects of prescribed burning in 3 selected watersheds in the South Fork Salmon River subbasin, Idaho. Three unburned watersheds adjacent to the treatment areas will remain unburned as controls. All 6 watersheds were surveyed for amphibians and invertebrates 1-2 times since the project began in 1999, and we propose to continue monitoring amphibians, invertebrates, and stream and riparian conditions in these 6 watersheds for 1-2 more years pre-treatment. We will also monitor periphyton communities during this time. Aquatic indicators in all watersheds (3 treatment, 3 control) will continue to be monitored for 1-2 years after the prescribed burn treatment.

To determine the effects of wildland fire on aquatic ecosystems, we will study 6 pairs of streams (burned and unburned) in two major drainages: Big Creek in the Middle Fork Salmon River subbasin, FC-RNR Wilderness, Idaho and Bitteroot River, in western Montana. We will compare watersheds with different burn severity (ground-verified BAER classification) and area (% watershed burned). In some watersheds, we will be able to resurvey streams that have amphibian and invertebrate data from before the wildland fires of 2000. For example, in the Big Creek drainage, 6 streams were surveyed for amphibians in 1994 and 1995 (Charles R. Peterson, unpublished data). Most of these streams have been monitored for invertebrates, periphyton, and stream conditions for >5 years by the Idaho State Stream Ecology Laboratory (Wayne Minshall, unpublished data). The riparian forests surrounding all 6 of these streams burned in August 2000. In this limited group of streams, we will compare amphibian density and biomass and invertebrate diversity and abundance before and after stand-replacing wildland fire. To evaluate and control for temporal differences in amphibian and invertebrate populations, we will compare populations in streams in nearby unburned watersheds over the same period. We will record environmental variables and habitat changes associated with fire in the burned and reference streams.

Oregon Study Areas: The prescribed fire study will be replicated in 3 watersheds with mixed coniferous/hardwood forests in the Siskiyou Mountains in southwestern Oregon. Based on discussions with fire ecologists and managers at Rogue River National Forest and Medford BLM, we hope that these agencies will schedule experimental prescribed burning for the spring of 2003. Similar to Idaho, the Oregon study will involve 1-2 years of pre-fire monitoring and 1-2 years of post-fire monitoring of aquatic indicators (amphibians, invertebrates, periphyton, stream conditions, and riparian forests). Reference ("control") streams in nearby unburned watersheds will be monitored in the same years as the watersheds subject to prescribed burn treatment. In western Oregon, the Aquatic Conservation Strategy of the Northwest Forest Plan (NWFP) provides riparian reserves of 1-2 tree heights away from all permanent streams. In 1997, a NWFP report, "Riparian Reserve Evaluation of Techniques and Censuses: Federal Guide for Watershed Analysis," suggested that management in riparian areas is feasible, including fuels reduction. Our site selection will depend on close consultation with BLM and Forest Service schedules of prescribed fires inside riparian reserves or adjacent slopes. However, if there are no burns in riparian reserves, the aquatic responses from prescribed fire on adjacent upslopes will also provide useful information. For example, unburned riparian areas likely buffer the stream from the effects of fire immediately after the burn, but streams may have a delayed response when spring runoff carries sediment and nutrients into the stream and peak discharge increases. On longer time scales, not burning riparian areas may result in changes in riparian forest structure and composition, changes in instream woody debris dynamics, and increased fire severity along riparian areas, especially during drought periods. Amphibians may still respond to upland burning, because metamorphic amphibians move into adjacent woods at the onset of fall rains and fire-associated mortality of terrestrial adults may reduce the number of reproductive individuals in a watershed.

The wildland fire component of this study will be replicated in Oregon in 2-3 locations, including watersheds in the Rogue and Umpqua rivers in southwestern Oregon (adjacent river basins), and the Wallowa Mountains in northeastern Oregon. In each of these areas, we will monitor amphibians and invertebrates in 6 paired streams (6 burned and 6 nearby unburned streams) annually for 2 years (2002-2003). Variation in burn severity, area of watershed burned, and time since burning will be analyzed. Watersheds will be grouped by time since burning to characterize recent (<1-5 years), and longer-term (>5-15 years) effects of fire on aquatic ecosystems (Minshall et al. 1997). We will attempt to have 3 burn streams in each group in each region.

For all study areas, we will quantify the following biotic and abiotic variables:

a. ***Amphibian Density and Biomass*****:** In each stream, we will sample 1 m belts in one randomly selected 200 m reach following a tested protocol (see Adams and Bury, in press). The number of belts is determined from a power analysis for reasonable accuracy (e.g., 25-35 in most Oregon streams). At each sampling transect belt, the average width will be used to calculate the area searched. All substrate will be turned over within each 1 m transect and all amphibians captured will be measured and weighed. Amphibian densities and biomass will be calculated allowing for analyses of within-stream variation, among-stream variation within treatment, and among-fire treatment variation. We will sample all streams once each year between June and August, allowing us to evaluate temporal variability (among years) in amphibian abundance and biomass.

b. ***Aquatic Invertebrate Communities*****:** The benthic invertebrate sampling protocol will follow methods used in similar stream studies (Minshall and Robinson 1998, Minshall et al. 1997) and described in standard stream ecology references (Platts et al. 1983, Merritt and Cummins 1996, APHA 1998, Davis et al. 2001). We will randomly select a 200-m reach in each stream, and establish 5 transects at 50-m intervals within the reach. We will collect benthic invertebrate samples from one location along each transect (n = 5 samples per reach) using a standard Surber sampler (0.10m^2, 250μm mesh) during summer base flow conditions. Each sample will be preserved in 75-100% ethanol for later identification (to genus) in the laboratory. Metrics derived from the invertebrate samples will include density, taxa richness and diversity, and functional feeding groups, and will be compared among years.

c. *Periphyton*: We will characterize benthic periphyton responses to different fire conditions based on algal biomass. In each stream, we will sample periphyton and calculate chlorophyll-a and ash-free dry mass (AFDM) using current methodology (Davis et al. 2001).

d. *Stream Conditions and Aquatic Habitats*: To evaluate prescribed fire effects on woody debris dynamics, we will establish instream plots adjacent to the riparian plots and measure all woody debris $\geq$ 10 cm large-end diameter and $\geq$ 1.0 m in length, and containing any portion within or suspended above the bankfull channel. Each sample will consist of two plots that are 100 m long (stream centerline) with a variable width (i.e., bankfull channel). Stream channel variables (e.g., wetted and bankfull widths, average depth, stream gradient) will also be sampled in each plot (see Corn and Bury, 1990). Woody debris, channel, and flow data will be collected during base flow conditions (mid-July through August).

At invertebrate sampling transects, we will measure physical stream factors including width, depth, current velocity, stream habitat type (e.g., riffle, run, pool), and the number of pieces of large woody debris. We will estimate discharge for the reach using width-depth profiles and current velocity measurements. Substratum size and embeddedness will be recorded at 50 random locations within the 200-m reach. Chemical measures (e.g., conductivity, pH) and temperature will be measured at one location within each reach. Water temperature recorders (Hobo type) will be installed to determine seasonal variation at all paired streams (= 36 recorders/region). One water sample per stream per year will be treated with concentrated sulfuric acid for later spectrophotometric analysis of total nitrogen and phosphorus concentrations.

e. *Riparian Forest Structure and Composition*: To understand how prescribed and wildland fire contribute woody debris to stream systems, we will also measure the riparian forest structure and composition in an area parallel to a stream with a perpendicular distance of 20 m. The number of samples for live trees and snags depends on the length of stream but is usually at least 6 per stream. Each sample consists of two 20 x 100 m rectangular plots with a center transect placed 10 m from the stream channel. Measurements are taken 10 m on either side of the transect (see Bate et al. 1999) with some additions. We will measure all live trees and snags $\geq$ 10 cm dbh and $\geq$ 1.0 m height. A riparian slope class is assigned to each plot.

Project Duration

The proposed research has an intensive field component in summers June-August 2002-2004 (Table 2). Laboratory work will be conducted Sept-December 2002-2004. Data analysis and report writing will occur in January-June, and final report completion is expected within 9 months of the last field season (August 2004). Thus, project will be completed and final report available by May 2005. Peer-reviewed journal articles will be submitted shortly afterward.

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